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Development of the automatic tunneling algorithm based on fuzzy logic for the microtunneling system

Jeong-Su Han[1], Jun-Hyeong Do[1], Zeungnam Bien[1],
Janghyun Nam[2], Taedong Park[2], and Kwang-Hyun Park[3]
[1]Department of EECS, Korea Advanced Institute of Science and Technology,
373-1 Guseong-Dong, Yuseong-Gu, Daejeon, 305-701, Korea
email: {pyodori, jhdo}@ctrsys.kaist.ac.kr, zbien@ee.kaist.ac.kr
[2]Network Infra Research Team, Technology Lab., Korea Telecom
463-1 Jeonmin-Dong, Yuseong-Gu, Daejeon, 305-811, Korea
email: {jhnam, tdpark}@kt.co.kr
[3]Human-friendly Welfare Robot System Engineering Research Center, KAIST
373-1 Guseong-Dong, Yuseong-Gu, Daejeon, 305-701, Korea
email: akaii@robotian.net

Abstract— **Microtunneling techniques play a crucial role in the construction of pipelines. This paper shows the automatic tunneling algorithm of microtunneling system using fuzzy logic technology to assist operators to assure the quality of microtunneling construction. To have effective output value of fuzzy controller, we slightly modified the conventional defuzzification methods. The proposed automatic tunneling algorithm shows good tunneling results comparable with those of experts.**

Keywords—**Microtunneling system, automatic control, intelligent control, fuzzy logic,**

I. INTRODUCTION

Microtunneling methods attract lots of attention recently, since the environmental and social impacts of pipeline construction can be significantly and cost-effectively reduced compared with other open-cut tunneling methods. Microtunneling is a trenchless construction method for installing pipelines [1], while the open-cut methods require long stretches of open trench, which causes extreme disruption to the community.

Until now, a few studies on microtunneling system have been reported [2], [3], [4], and these studies have been restricted to steering control of microtunneling system [2], and forward detection method of obstacles [3], [4]. Study on automatic tunneling control of the microtunneling system has not been known to society.

Operator's skill plays a critical role in the success of microtunneling construction which has numerous parameters to be monitored and to be responded to in the course of operation. It is, however, very difficult to concentrate on the operation for a long time even if he/she is an expert in this field. Therefore we need to develop an automatic tunneling algorithm to assist an operator to assure the quality of construction.

Since the microtunneling systems have been successfully controlled based on the operator's own experiences and these experiences can be easily incorporated to fuzzy logic, we adopt the fuzzy logic technology for developing an automatic tunneling algorithm. Furthermore, fuzzy logic is very useful when the mathematical model of the controlled system is difficult to be obtained for the microtunneling system.

This paper shows the automatic tunneling algorithm of microtunneling system by using fuzzy logic technology. We briefly explain the microtunneling system in Section 2, and the proposed algorithm will be covered in detail in Section 3. In Section 4, the experimental results are presented to show the effectiveness of the proposed algorithm and the concluding remarks follow in Section 5.

II. MICROTUNNELING SYSTEM

Microtunneling is an accurate, laser guided method for installing pipelines in varied soil conditions from flowing soft ground to hard rock. Microtunneling system consists of four basic components: microtunneling boring machine (MTBM), slurry circulation system, pipejacking system, and control system (Fig. 1). Its operation can be briefly described as follows: MTBM pilots the course and excavates the ground. Simultaneously, slurry is pumped to the MTBM, mixed with the spoil and pumped to the surface for separation. As with conventional pipejacking, hydraulic cylinders are used to advance the pipeline and the MTBM.

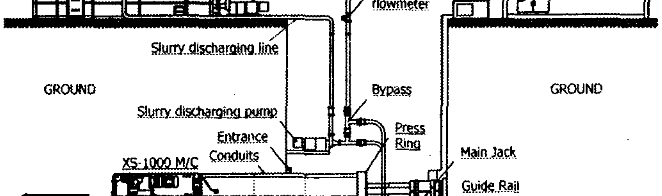


Fig. 1. Microtunneling system (*This microtunneling boring machine, XS-1000 M/C, was developed by Korea Telecom and Naontech in Korea.*)

III. THE AUTOMATIC TUNNELING ALGORITHM

The automatic tunneling algorithm includes control of torque/pipejacking thrust, and control of slurry charging/discharging pressure. Torque/pipejacking thrust is controlled to maximize the tunneling speed bounded to capacity of slurry circulation system and maximum torque of a cutter. Slurry charging/discharging pressure is controlled to properly deliver spoil out of MTBM, and these control effects may affect each other. For example, the more pipejacking thrust applies to the microtunneling system, the more spoil is obtained. Then an operator raises slurry charging pressure to extract muck out of MTBM. Fig. 2 shows the overall structure of the proposed automatic tunneling algorithm.

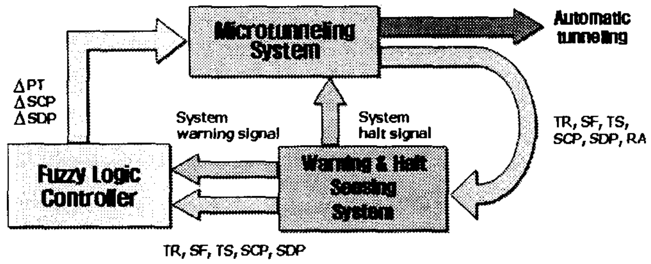


Fig. 2. Structure of the proposed automatic tunneling algorithm (*We abbreviate "Torque" to TR, "Slurry Flow" to SF, "Tunneling Speed" to TS, "Slurry Charging Pressure" To SCP, "Slurry Discharging Pressure" to SDP, "Rolling Angle" to RA, and "Pipejacking Thrust" to PT*)

A. *Fuzzy Logic Controller*

We set input variables of fuzzy logic controller as TR, SF, TS, SCP, SDP, and output variables as the change of amount of PT, SCP, SDP in Fig. 2. We extracted tunneling rules from interviewing with lots of experts and then categorized these rules according to the ground conditions. Table 1 shows partial fuzzy rules when the ground condition is hard rock.

TABLE I PARTIAL FUZZY RULES FOR MICROTUNNELING SYSTEM WHEN THE GROUND CONDITION IS HARD ROCK (*We abbreviate "Low" to L, "Middle" to M, "High" to H, and "Very High" to VH*)

Input variables (IF)					Output variables (Then)		
TR	SF	TS	SCP	SDP	ΔPT	ΔSCP	ΔSDP
L	M	L	M	M	VH	M	M
L	M	M	M	M	H	M	M
M	L	M	M	M	L	H	H
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
H	H	H	M	M	L	M	M

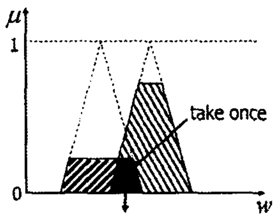
B. *The Proposed Defuzzification Method*

We modified the conventional defuzzification method. Center-of-Gravity method (1) gives an effective defuzzified result but takes time to calculate the overlapped area which is not applicable for real time application such as our system. Center-of-Sums method (2) gives faster defuzzified result while the result is calculated for all overlapped areas and is sometimes inefficient. The modified defuzzified method (3) gives faster and similar result of Center-of-Gravity because it only scans the overlapped intervals to find the minimum overlapped area, and it takes only twice overlapped area into account for calculation of output value. Fig. 3 shows the modified defuzzification method compared with other two conventional defuzzifiers.

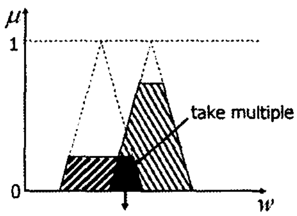
$$U_0 = \frac{\int w\mu(w)dw}{\int \mu(w)dw} \tag{1}$$

$$U_0 = \frac{\int w\sum_{j=1}^{l}\mu(w)dw}{\int \sum_{j=1}^{l}\mu(w)dw} \tag{2}$$

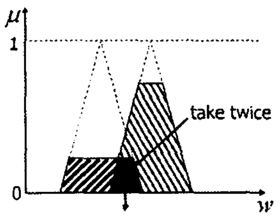
$$U_0 = \frac{\int w\left(\arg\min_{l}\sum_{j=1}^{l}\mu(w)\right)dw}{\int \left(\arg\min_{l}\sum_{j=1}^{l}\mu(w)\right)dw} \tag{3}$$



(a) Center-of-Gravity method



(b) Center-of-Sums method



(c) The modified defuzzification method

Fig. 3. The comparison between conventional defuzzification methods and the proposed defuzzification method

In the proposed controller, we adopt triangular membership functions in fuzzification and defuzzification, and Mamdani's min-max operation is used as an inference method.

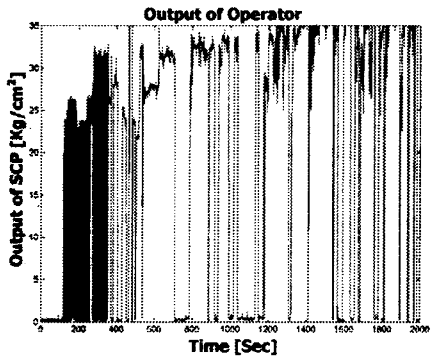
C. Warning and Halt Sensing System

To cope with unexpected cases, the system always monitors the variation of crucial parameters. When extreme situation occurs, the halt signal immediately stops the operation of microtunneling system and/or the warning signal alerts operator. We can summarize these emergency cases as follows.

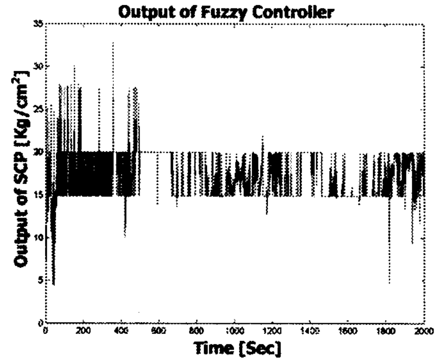
- Rolling angle is beyond the limit
- torque is beyond the limit
- slurry flow is less than limit
- the difference between SCP and SDP is beyond the limit
- SCP is beyond the limit
- SDP is beyond the limit.

IV. EXPERIMENTAL RESULTS

To show the effectiveness of the proposed automatic tunneling algorithm, we compare the output performance from the real operation with the output performance of fuzzy controller. As shown in Fig. 4, the proposed fuzzy controller gives consistent result with that of an expert. We also applied the fuzzy controller to real working system and concluded that the proposed fuzzy controller works as an expert in various ground condition and gives consistent sensing ability in the emergency situation.



(a) An output of SDP from operator



(b) An output of SDP of the proposed fuzzy controller

Fig. 4. The comparison between conventional defuzzification methods and the proposed defuzzification method

V. CONCLUSION

Microtunneling techniques will play an important role in the future pipeline construction. We proposed fuzzy logic controller to develop an automatic tunneling system which assists operators to assure the quality of microtunneling construction.

The proposed automatic tunneling algorithm shows good tunneling results comparable with those of expert and has ability to perceive the emergency situation immediately. Furthermore this algorithm has applicability to various ground condition and MTBM by easily editing some parameters. As a further work, it is necessary to develop steering control of the proposed microtunneling system for full automation.

ACKNOWLEDGMENT

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